Technical Note N-634

HEAT DISSIPATION FROM ABOVE GROUND SHELTERS

BY

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25 September 1964

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Y-F011-05-02-341

Type C

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ABSTRACT

Above ground structures which have been officially designated as fallout shelters pose a number of ventilation problems which require attention to insure that the thermal environment of the protected area will be habitable. The various materials and configurations of the structures and the effect of solar radiation requires that the heat transfer through the walls and other surfaces be considered separately. To provide heat transfer data for those structures which are of thick wall construction, a widely accepted analytical solution was programmed for the 1620 computer.

A modified psychrometric chart was developed so the sensible heat factor technique can be used to determine ventilation requirements for above ground shelters subjected to unusual climactic conditions.

Sample calculations for a 500-man shelter located in St. Louis, Missouri show that the maximum heat gain through the thick walls is only 1.79 per cent of the human load and the heat loss through the floor is 3.33 per cent of the human load. The people in this case contribute almost the entire net heat load. Calculations also indicate that the required ventilation rate is almost twice that required for the same shelter in Sacramento, California. This difference underscores the fact that frequently quoted rates from 3 to 18 cfm per person can be misleading unless properly qualified.

Continued work on this task is directed toward the accumulation of more data on heat transfer through walls of heavy construction, and heat loss through the floor. Further modifications to the psychrometric chart may be needed and the inside design conditions are to be investigated with respect to comfort vs. economy.

INTRODUCTION

Many buildings now in existence have been designated as fallout shelters by Civil Defense authorities, but only when they are properly ventilated can they realistically be classified as protective areas. Most of the designated buildings are of conventional heavy construction with masonry walls 12 to 16 inches thick; however, in the event of a nuclear threat it would be possible to thicken many of the walls with sand bags, rows of concrete block or extra layers of concrete. Therefore, the first phase of this study on ventilation for above ground shelters is directed toward thick composite wall construction. Recognizing the likelihood of non-uniformity in the walls of such shelters, the solution treats the walls, roof and floor as separate components of any thickness or material giving complete flexibility to the solution.

The effective temperature in a protective shelter above ground is influenced by the following factors:

a. Internal heat load

1. Humans are the prime source of both sensible and latent heat inside the shelter. Items such as lights, electronic equipment and fan motors produce sensible heat only.

b. Thermal characteristics of the soil

1. Above ground shelters having floors in direct contact with the ground lose heat through the floor to the soil. The rate of heat transfer depends on the thermal characteristics of the soil and the difference between the floor and soil temperatures. During the first few hours of occupancy the rate of transfer is quite high but it rapidly decreases and approaches a constant value in 10 to 20 days.

c. Thermal characteristics of the building materials

1. The thermal characteristics of the building materials do not vary much from one shelter to another because in all cases the mass of the materials is necessarily high for protection against nuclear radiation.

d. Sol-Air temperature

1. The sol-air temperature can be readily calculated and does not vary a great deal from one location to another within the latitudes bounding the Continental United States of America.

e. Condition of the outside air

1. The design condition of the outside air to be used for ventilation is based on climatological data gathered over a long period of time and plays an important part in controlling the effective temperature inside the shelter.

The factors mentioned here involve numerous variables and it should be emphasized that the problem is complex and it is highly unlikely that it will ever be resolved into a simple set of rules or tables applicable to all shelters.

For this report, only walls of 3-foot thickness have been considered, but the analysis can be applied to any thickness providing there are no more than 3 layers of materials.

SOLUTION DESCRIPTION

The ventilation requirement for an above ground structure is based on the heat gain through the exposed areas plus the internal heat load minus the heat discharged through the floor. If the ventilating air has the effect of adding heat rather than removing heat it should then be kept to a minimum and some form of refrigeration employed.

Heat Gain Through Exposed Walls and Roofs

Periodic heat flow through composite walls and roofs has been thoroughly explored by Mackey and Wright,[1] and the results of their work form the basis for the cooling load tables[2] adopted by the American Society of Heating, Refrigerating, and Air Conditioning Engineers. These tables are confined to conventional walls and roofs; consequently, for thick wall construction it was necessary to compute the cooling load by utilizing the mathematical solution of Mackey and Wright. In this solution the harmonic decrement factor (λ) and the harmonic lag angle (ϕ), (given in Appendix A), are arithmetically cumbersome, thus these parameters were programmed for the 1620 computer. Equations to determine the temperature of the inside wall surface (T_o) and the instantaneous rate of heat transfer (Q/A) (given in Appendix A) were also included in the computer program.

Complete details of the 1620 computer program are shown in Appendix A making it possible for anyone with access to this computer to determine the periodic heat flow for any wall without recourse to the original solution. For convenience, 24 walls consisting of eight cases of concrete-earth configurations with three types of earth for each case have been analyzed for two inside air temperatures of 85 F and 90 F. The eight cases are shown in Figures 1B, 2B, 3B and 4B of Appendix B.

Cases V and VI would most likely represent roof constructions. Cases VII and VIII, similar to V and VI, might represent walls where the earth is in the form of sand bags or held in place by plywood which would have little thermal effect on a thick wall. The characteristics of the three types of earth (labelled A, B, and C) are given in Table I. A reference to Case IA means Case I configuration with type A earth. The thermal characteristics for concrete are also given in Table I.

Table I. Properties of Earth and Concrete

Material	Type	k	p	c	kpc	Moisture (%) of dry wt.
Earth	A-silty clay	.17	75.3	.193	2.47	5
	B-clay sand	.66	107	.163	11.5	5
	C-clay sand	1.74	107	.163	30.4	20
Concrete	Sand and gravel aggregate	1.0	140	.25	--	--
	Cinder aggregate	.30	100	.20	--	--

The computer produced a ponderous set of results for the two temperatures, but it was possible to group the results into the two tables shown in Appendix C. Using these tables a design engineer can determine for each exposure the maximum inside wall surface temperature, the maximum heat transfer through the walls (positive or negative) in BTU/hr/sq ft, and the corresponding time of day at which these values occur. Of course, his parameters must satisfy the conditions imposed on the development of the tables -- otherwise the computer program is required. For conventional walls the tables in the ASHRAE guide may be used.

Heat Loss Through The Floor

For a plane surface in soil large enough so that edge effects can be neglected and held at a constant temperature differential ΔT above the initial soil temperature, the instantaneous rate of heat transfer is given by the formula[3]

$$q = \frac{.567\sqrt{k\rho c}\ \Delta T}{\sqrt{t}} \qquad (a)$$

where q is the heat transfer from one side of the plane surface in BTU/hr/ft^2

k = thermal conductivity of the soil, BTU/hr ft F

p = density of the soil, lb/ft^3

c = specific heat of the soil, BTU/lb F

ΔT = temperature difference between the plane surface and the initial temperature of the soil

and

t = time in hours

The kpc values of different soils are readily available permitting quick comparisons of their potential heat absorption rates.

Formula (a) is somewhat awkward to use but Raber, Boester and Hutchinson[4] have plotted it for convenience, as shown in Figure 1. The use of the formula assumes a constant ΔT which would not be the case during the initial period of occupancy when the floor temperature would be rising. However, the accuracy of the method increases with the time of occupancy, so for periods of 10 days or more the results are quite reasonable. For shelters under continual use, the soil may have absorbed sufficient heat to nullify its effectiveness as a heat sink, thereby obviating the necessity for this calculation.

Internal Heat Load

People, lights, stoves and electronic equipment will all add to the internal heat load; however, under the austere conditions specified for fallout shelters the people will be the prime contributors. The sensible and latent heat emitted by the human body varies with clothing, the degree of physical activity and the wet and dry bulb temperatures. It is clear that body heat loss cannot be accurately forecast, but for illustration purposes the sensible heat loss will be estimated at 100 BTU/hr and the latent heat loss at 300 BTU/hr assuming people at rest. If the occupants were working these values might be doubled or tripled, so estimates of the human heat load must be made with some factor of safety. The heat produced by auxiliary equipment will be almost entirely sensible.

Net Heat Load

The net heat which must be removed from the shelter will be the algebraic summation of heat transferred through the roof, walls, floor and the internal heat load. The net amount must be divided into sensible and latent heat so that the condition and amount of the ventilating air can be properly determined. If outside air cannot meet the required condition then no amount of air, within practical limits, can cool the shelter without refrigeration. The erroneous assumption is sometimes made that the quantity of air is the sole criterion in ventilation design.

Sensible Heat Factor

The conditions which will most likely prevail in shelters with thick walls result in low sensible heat factors which can not be handled graphically on all psychrometric charts. To overcome this problem, a modified psychrometric chart (Figure 2) was developed to include low sensible heat factors and also the isotherms of several effective temperatures. Through the use of this chart the condition of ventilating air which will meet the heat removal demands of the shelter can be graphically determined and its rate of flow subsequently calculated. Also, the refrigeration requirements can be determined.

ILLUSTRATIONS

To clarify this procedure, illustrations are presented which are concerned with two identical shelters located in different cities.

Illustration No. 1

Consider an above ground, 500-man shelter which is normally unoccupied and located in St. Louis, Missouri. The inside dimensions are 70- by 70- by 10-feet. The roof is Case VA and the walls are Case IA. The floor is a concrete slab on type A earth. If the shelter is occupied by 500 persons for two weeks and the inside conditions are not to exceed 90 dry bulb and 85 effective temperature, how much ventilation is required; what must be the condition of the air entering the shelter; and how many tons of refrigeration are required?

Solution

1. The first step is to establish the time of day at which the maximum cooling load occurs. This requires a trial and error method but a conclusion can soon be reached assuming that adequate heat transfer data is available. For example, the heat gain through a large flat roof will usually be much larger than that through the walls and when the

internal load is essentially constant, as in illustration No. 1, the roof becomes the determinant factor. By referring to Table IC (Appendix C) it can be seen that the maximum roof load of 0.751 BTU/hr sq ft, resulting from a peak sol-air temperature in the early afternoon of the previous day, will occur at 12 noon. The thick wall of heavy construction is very effective in modulating the cyclic temperature changes of the inside wall surface, consequently the heat transfer rates at 10 AM and 2 PM are practically the same as at 12 noon. Note that the north and south exposures have a negative heat transfer which is due to the high inside temperature and the degree of solar radiation on those surfaces. If the 12 noon values are applied to the areas in the given problem the net heat gain through walls and roof amounts to 3579 BTU/hr.

2. The second step is to determine the heat loss through the floor which can be done through the use of Figure 1 or by using formula (a). The value for kpc is given in Table I and the time given is 336 hours (two weeks). In determining a value for ΔT the soil temperature was assumed* to be 57 F which is the well water temperature in the St. Louis area.[6] The floor surface temperature, which is originally at soil temperature, rises rapidly after occupancy and then levels off in an asymptotic manner as it approaches the room air temperature. For practical and conservative purposes it can be considered a constant value approximately five degrees below the room air temperature. For this illustration the floor temperature would therefore be 85 F and $\Delta T = (85-57)$ giving a total heat loss to the soil of 6660 BTU/hr.

3. The third step is estimating the internal load which in the given illustration involves humans only. Assuming the occupants are sitting or reclining in light clothing the sensible load has been estimated at 50,000 BTU/hr and the latent load 150,000 BTU/hr.

4. The net sensible heat load is therefore 3,579 - 6,660 + 50,000 = 46,919 BUT/hr and the net latent heat is 150,000 BTU/hr.

5. The sensible heat factor $= \dfrac{\text{sensible heat}}{\text{sensible heat + latent heat}}$

$$= \frac{46{,}919}{46{,}919 + 150{,}000} = 0.238$$

6. Reference is now made to the modified psychrometric chart (Figure 2) and the following steps are taken:

a. Notice the location of reference point "A" which is an integral part in the construction of the original psychrometric chart.

*This assumption is based on information given in the ASHRAE guide[7] for heating load calculations. For an actual shelter local soil temperatures should be obtained.

b. Locate the inside design conditions of 90 dry bulb and 85 effective temperature and call it "B."

c. Locate the outside design temperature for St. Louis, 94 dry bulb and 77 wet bulb and call it "C."

d. Draw a horizontal line from "C" to the saturation line; call it "CD." When the air at condition "C" is cooled it will move left along this line to "D" and then down the saturation line.

e. Draw a line from "A" to the sensible heat factor value of .238 and call it "AE." This establishes the slope which the air will follow as it heats up inside the shelter.

f. Draw a line through "B," parallel to "AE" cutting "CD" at "F" which represents the required entering condition.

7. When the air at condition "C" (St. Louis design) is cooled either by nature or refrigeration it must reach the condition at point "F" in order to handle the internal load. The entering air temperature at "F" has a dry bulb temperature of 82.2 F and a wet bulb temperature of 73.8 F.

8. The quantity of air required is calculated by the following formula

$$\text{cfm} = \frac{\text{sensible heat}}{1.08 \times (\text{"B" dry bulb} - \text{"F" dry bulb})}$$

For this illustration the cfm equals 5560 total or 10.1 cfm/person. If the entering air temperature moves to the left of "F" the same quantity of air will cause the inside condition to move to the left of "B" producing a more comfortable condition in the shelter. If the entering air temperature moves to the right of "F" refrigeration is needed.

9. The refrigeration required to cool the air from the outside design temperature to the condition at "F" can be computed through the use of enthalpies. The modified psychrometric chart shows the enthalpies for points "C" and "F" to be 40.2 BTU/lb and 37.3 BTU/lb respectively. The refrigeration required is therefore

$$5560 \times \frac{.075}{200} \times (40.2 - 37.3) = 6.06 \text{ tons}$$

Illustration No. 2

The second illustration assumes that all criteria for the shelter are to be the same as in illustration No. 1 except that the shelter is located in Sacramento instead of St. Louis. This means that the outside design temperature will be 94 F dry bulb and the wet bulb will be 69 F.

The sensible heat factor will remain unchanged and by following the steps in the previous solution the condition of the entering air is located at point "H" (73 db and 62.1 wb). Further calculations show that the required cfm equals 2550 total or 5.1 cfm/person, which is approximately one-half that required for St. Louis. The refrigeration required to cool the air from the outside design temperature to the entering air condition at "H" would be 4.97 tons.

In comparing the calculations for the two cities note that the outside dry bulb temperature of 94 F is common to both cities so the basic design criteria are identical in the two cases except for the outside wet bulb temperature. The notable effect of this one exception emphasizes the difficulty in simplifying shelter ventilation calculations which are characterized by a multitude of variables.

FUTURE WORK

Future work on the task will be directed toward obtaining more data on heat transfer through heavy construction and more information on heat loss through the floor. Further modifications to the psychrometric chart are expected and also some arguments on whether it is economically advisable to hold the inside temperature at 85 effective temperature and 90 dry bulb, or at a more comfortable condition.

ACKNOWLEDGEMENTS

The work done by Mr. Alan Mettler in setting up the computer program is gratefully acknowledged.

The author wishes to express his appreciation to Mr. Sheldon L. Phelps for valuable assistance in condensing the results of the computer program into a more useable set of tables.

Thanks are also extended to Mr. Ronald J. Zablodil, LT David F. Sampsell and Mr. Charles E. Herndon for editing the report and offering a number of excellent suggestions.

REFERENCES

1. C. O. Mackey and L. T. Wright, Jr. "Periodic Heat Flow Composite Walls or Roofs." Transactions, ASHVE, Vol. 52, 1946, pp 289-291.

2. ASHRAE Guide and Data Book, Fundamentals and Equipment. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. New York, 1963. pp 473-476.

3. B. F. Raber, et al, "How to Analyze Earth as a Heat Source." Heating, Piping & Air Conditioning, March 1948, p 85.

4. Ibid, p 86.

5. ASHRAE Guide and Data Book, Fundamentals and Equipment. American Society of Heating, Refrigerating and Air-Conditioning, Inc. New York, 1963. pp 107-108.

6. U. S. Naval Civil Engineering Laboratory Technical Note N-523, Analyses of Heat Dissipation Techniques for Protective Shelters, by J. M. Stephenson, C. L. Herndon. Port Hueneme, Calif., July 1963, Figure 2. Unclassified.

7. ASHRAE Guide and Data Book, Fundamentals and Equipment. American Society of Heating, Refrigerating and Air-Conditioning, Inc. New York, 1963. p 451.

Appendix A

PERIODIC HEAT FLOW THROUGH COMPOSITE WALLS AND ROOFS

Alan Mettler

INTRODUCTION

For a given structure made up of four walls and a roof, each wall and roof of which is composed of two or more layers, the temperature, rate of heat transfer and time for each inside surface can be computed. In order to calculate these variables various parameters must be known. These are: thermal conductivities, thicknesses, specific heats and densities of the layers, the air film coefficients of heat transfer, the average daily sol-air temperature and the actual sol-air temperature.

Three computer programs have been written which treat the two layer and three layer cases. One program solves the problem for the two layer case; the remaining two programs solve the three layer case. The three layer case was broken into two programs because of the length of the equations involved.

PROGRAM DESCRIPTION

a. Program One computes parameters used by Program Two. Program Two (three layer case) and Program Three (two layer case) compute nine sets of data for each wall and roof on one pass, then pause, at which time the operator may load a new set of parameters and push start.

It is desired to compute n sets of data ($n \neq 9$) then one simply changes the limits of the innermost loop. Suppose n = 12 then change statement 5 + 4 from D07I = 1,9 to D07I = 1,12. If one would like to have data, say on two walls, then the limits on the outer loop should be changed, i.e., statement 4 becomes D07J = 1,2.

Running time for nine sets of data per structure (4 walls and a roof) in the three layer case is approximately 1.5 minutes on the IBM 1620 Computer. For the two layer case the time is approximately 1 minute. The costs are about $1.00 and $.65, respectively.

b. SYMBOLS

Math Symbols	Program Symbols
c_1	CL
c_m	CM
c_o	CO
h_1	HL
h_o	HO
k_1	XKL
k_m	XKM
k_o	XKO
L_1	XLL
L_m	XLM
L_o	XLO
t_e	TE
t_m	TM
t_M	TMM
t_o	TO
λ	XLAM
θ	THT
φ	PHI
ρ_1	RHOL
ρ_m	RHOM
ρ_o	RHOO

c. INPUT

All input variables are F type format and have a field length of 10 columns.

Input to Program 1

Card 1	XKO, XKL, XKM, HO, HL
Card 2	CO, CL, CM, RHOO, RHOL, RHOM
Card 3	XLO, XLM, XLL

Input to Program 2

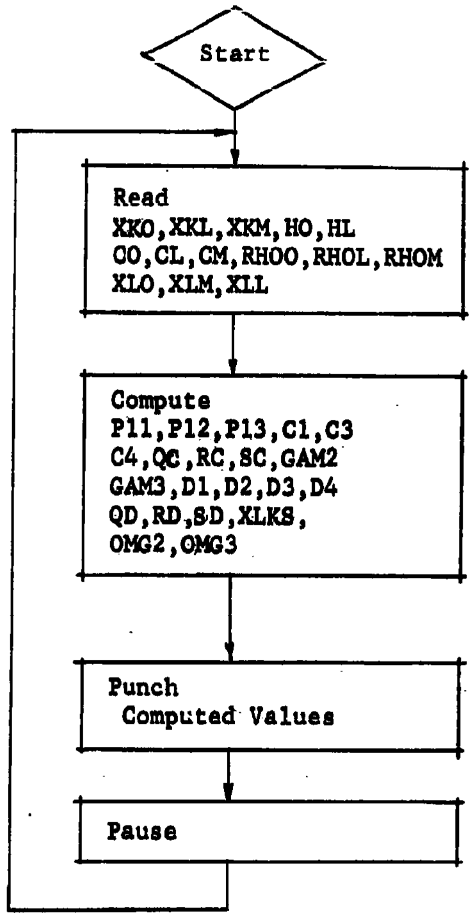
Output from 1 as is

Card 5	T1, TM
Card 6	TE, THT
.	
.	
.	
Card 14	TE, THT
Card 15	T1, TM
Card 16	TE, THT
.	
.	
.	
Card 24	TE, THT

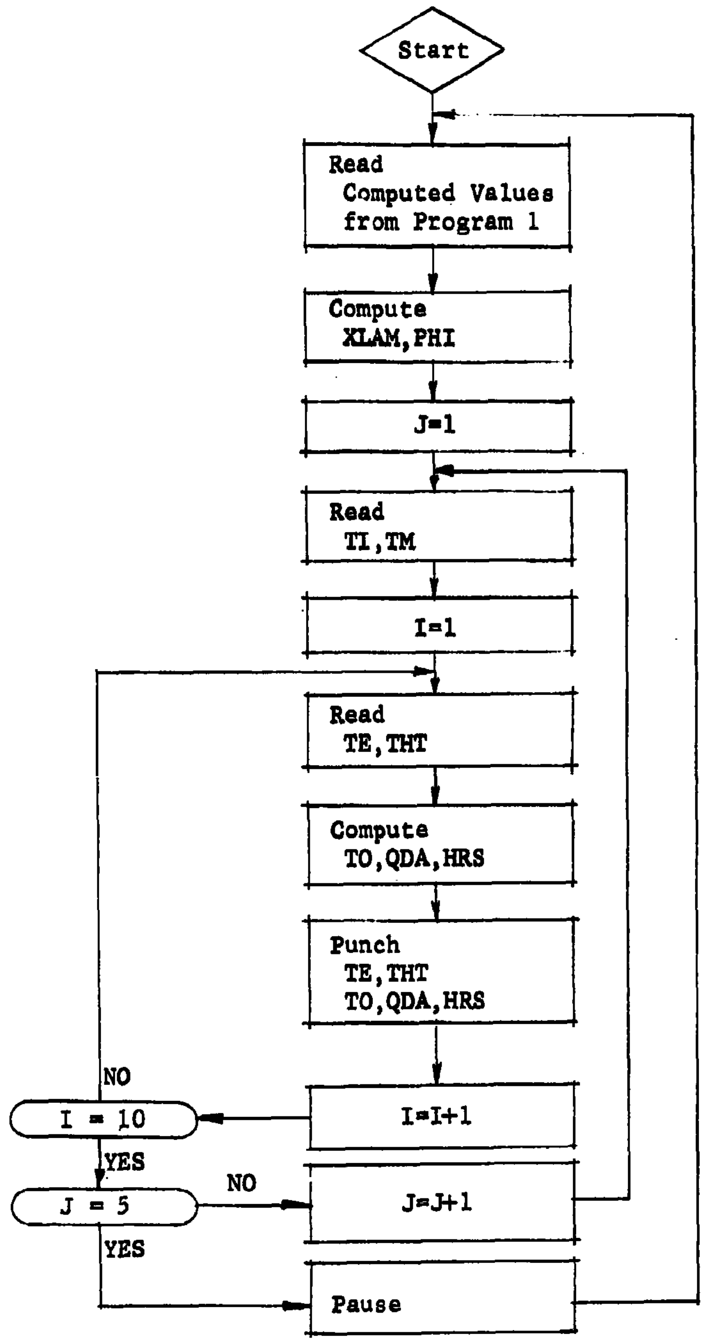
Input to Program 3

Card 1	XKO, XKL, XKM, HO, HL
Card 2	CO, CL, CM, RHOO, RHOL, RHOM
Card 3	XLO, XLM, XLL
Card 4	T1, TM
Card 5	TE, THT
.	
.	
.	
Card 13	TE, THT
Card 14	T1, TM
Card 15	TE, THT
.	
.	
.	
Card 23	TE, THT

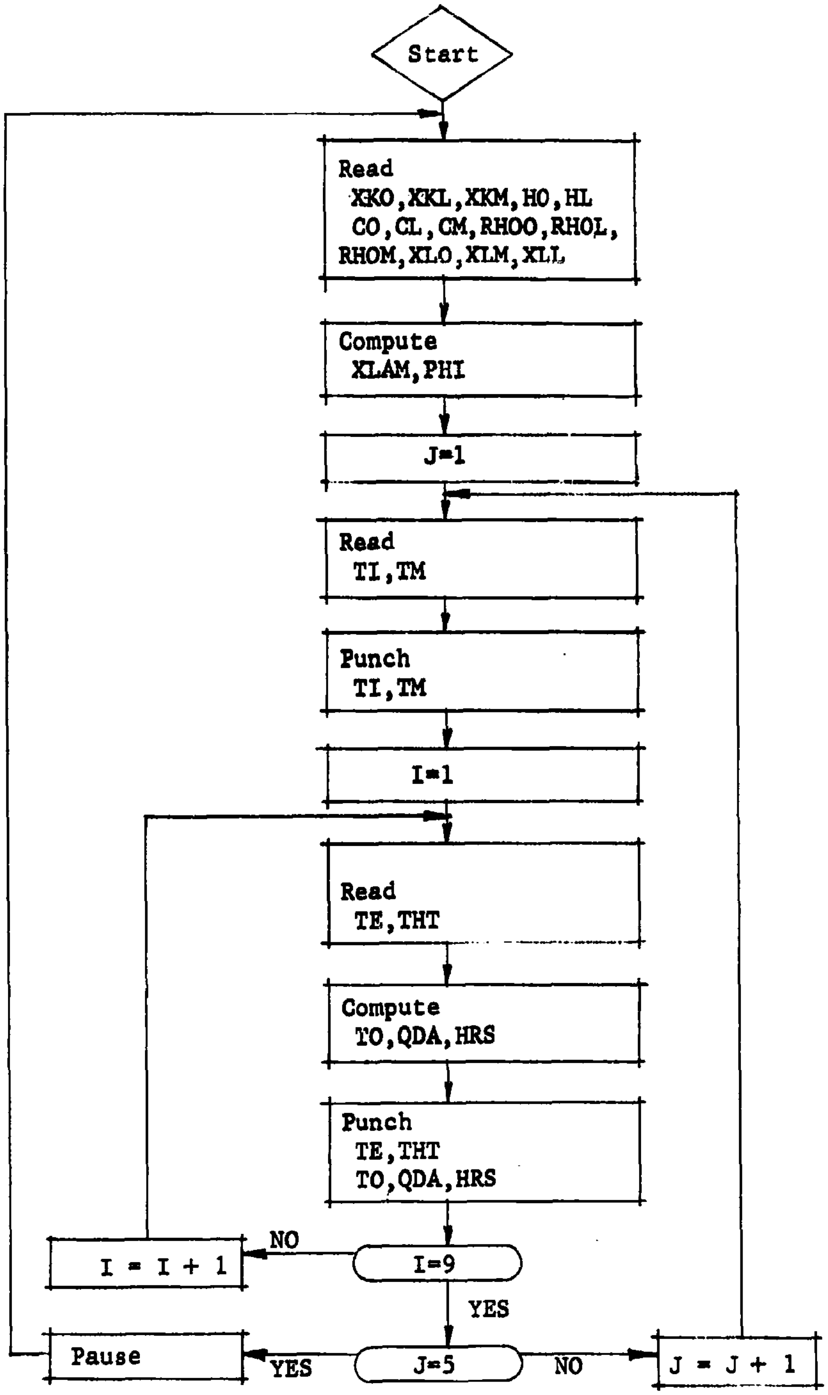
d. FLOW CHART FOR PROGRAM 1 (Three Layer Case)



e. FLOW CHART FOR PROGRAM 2 (Three Layer Case)



f. FLOW CHART FOR PROGRAM 3 (Two Layer Case)



EQUATIONS OF PROBLEM

a.) EQUATIONS COMMON TO BOTH TWO LAYER AND THREE LAYER CASES

$$\pi_1 = \frac{h_0}{h_2}\ ; \quad \pi_2 = \sqrt{\frac{0.1309\,\rho_0 C_0}{k_0}}\,L_0\ ; \quad \pi_3 = \frac{k_0}{h_0}\sqrt{\frac{0.1309\,\rho_0 C_0}{k_0}}\ ;$$

$$\Gamma_2 = \sqrt{\frac{0.1309\,\rho_2 C_2}{k_2}}\,L_2\ ; \quad \Gamma_3 = \frac{k_2}{h_2}\sqrt{\frac{0.1309\,\rho_2 C_2}{k_2}}\ ; \quad C_1 = \cos\pi_2 \cosh\pi_2 + \sin\pi_2 \sinh\pi_2\ ;$$

$$C_2 = \cos\pi_2 \cosh\pi_2 - \sin\pi_2 \sinh\pi_2\ ; \quad C_3 = \sin\pi_2 \cosh\pi_2\ ; \quad C_4 = \cos\pi_2 \sin\pi_2$$

$$D_1 = \cos\Gamma_2 \cosh\Gamma_2 + \sin\Gamma_2 \sinh\Gamma_2\ ; \quad D_2 = \cos\Gamma_2 \cosh\Gamma_2 - \sin\Gamma_2 \sinh\Gamma_2$$

$$D_3 = \sin\Gamma_2 \cosh\Gamma_2\ ; \quad D_4 = \cos\Gamma_2 \sinh\Gamma_2\ ; \quad Q_D = \sqrt{\frac{2}{(D_3/\Gamma_3 + D_1)^2 + (D_4/\Gamma_3 + D_2)^2}}$$

$$Q_C = \sqrt{\frac{2}{(C_3/\pi_3 + C_1)^2 + (C_4/\pi_3 + C_2)^2}}\ ; \quad S_D = (D_2 - 2\Gamma_3 D_3)(D_3/\Gamma_3 + D_1) - (D_1 + 2\Gamma_3 D_4)(D_4/\Gamma_3 + D_2)\ ;$$

$$R_D = (D_1 + 2\Gamma_3 D_4)(D_3/\Gamma_3 + D_1) + (D_2 - 2\Gamma_3 D_3)(D_4/\Gamma_3 + D_2)\ ;$$

$$S_C = (C_2 - 2\pi_3 C_3)(C_3/\pi_3 + C_1) - (C_1 + 2\pi_3 C_4)(C_4/\pi_3 + C_2)\ ;$$

$$R_C = (C_1 + 2\pi_3 C_4)(C_3/\pi_3 + C_1) + (C_2 - 2\pi_3 C_3)(C_4/\pi_3 + C_2)\ ;$$

b.) EQUATIONS FOR TWO LAYER CASE

$$\phi = \tan^{-1}\frac{(C_3/\pi_3 + C_1) - (C_4/\pi_3 + C_2)}{(C_3/\pi_3 + C_1) + (C_4/\pi_3 + C_2)}$$

$$+ \tan^{-1}\frac{\left[(D_3/\Gamma_3 + D_1) - (D_4/\Gamma_3 + D_2)\right]\left[R_D Q_D^2 + \pi_1 R_C Q_C^2\right] - \left[(D_3/\Gamma_3 + D_1) + (D_4/\Gamma_3 + D_2)\right]\left[S_D Q_D^2 + \pi_1 S_C Q_C^2\right]}{\left[(D_3/\Gamma_3 + D_1) + (D_4/\Gamma_3 + D_2)\right]\left[R_D Q_D^2 + \pi_1 R_C Q_C^2\right] - \left[(D_3/\Gamma_3 + D_1) - (D_4/\Gamma_3 + D_2)\right]\left[S_D Q_D^2 + \pi_1 S_C Q_C^2\right]}\ ;$$

$$\lambda = \frac{2}{\sqrt{\left(R_0 \frac{Q_0}{Q_c} + R_c \frac{Q_c}{Q_0}\right)^2 + \left(S_0 \frac{Q_0}{Q_c} + \pi_1 S_c \frac{Q_c}{Q_0}\right)^2}}$$

$$L/k = L_0/k_0 + L_\ell/k_\ell$$

$$(t_0)_{\theta + \frac{\phi_1}{15}} = t_M + \lambda_1 \left[(t_e)_\theta - t_m\right]$$

$$t_m = t_i + \frac{0.606(t_m - t_i)}{0.856 + \frac{L}{k}}$$

$$q/A = 1.65(t_o - t_i)$$

c) EQUATIONS FOR THREE LAYER CASE

$$\Omega_2 = \sqrt{\frac{0.1309\, \rho_m C_m}{k_m}}\, L_m \ ; \quad \Omega_3 = \frac{k_m}{h_0}\sqrt{\frac{0.1309\, \rho_m C_m}{k_m}}\, L_m \ ;$$

$$W_1 = \cos\Omega_2 \cosh\Omega_2 + \sin\Omega_2 \sinh\Omega_2$$

$$W_2 = \cos\Omega_2 \cosh\Omega_2 - \sin\Omega_2 \sinh\Omega_2$$

$$W_3 = \sin\Omega_2 \cosh\Omega_2 \ ; \quad W_4 = \cos\Omega_2 \sinh\Omega_2 \ ;$$

$$Y_W = W_1 W_3 + W_2 W_4 \ ; \quad Z_W = W_2 W_3 - W_1 W_4 \ ;$$

$$\psi = \tan^{-1}\left\{\frac{\left[\left(D_3/\sqrt{3} + D_1\right) - \left(D_4/\sqrt{3} + D_2\right)\right]\left\{\frac{R_0 Q_0^2}{2} - \pi_1 \Omega_3 \frac{\rho_W^2}{2}\left[\left(W_3 + W_4\right)\delta\cos\epsilon - \left(W_3 - W_4\right)\delta\sin\epsilon - Y_W\right]\right\}}{\left[\left(D_3/\sqrt{3} + D_1\right) + \left(D_4/\sqrt{3} + D_2\right)\right]\left\{\frac{R_0 Q_0^2}{2} - \pi_1 \Omega_3 \frac{\rho_W^2}{2}\left[\left(W_3 + W_4\right)\delta\cos\epsilon - \left(W_3 - W_4\right)\delta\sin\epsilon - Y_W\right]\right\}}\right.$$

$$\left.\frac{- \left[\left(D_3/\sqrt{3} + D_1\right) + \left(D_4/\sqrt{3} + D_2\right)\right]\left\{\frac{S_0 Q_0^2}{2} - \pi_1 \Omega_3 \frac{\rho_W^2}{2}\left[\left(W_3 - W_4\right)\delta\cos\epsilon - \left(W_3 + W_4\right)\delta\sin\epsilon - Z_W\right]\right\}}{+ \left[\left(D_3/\sqrt{3} + D_1\right) - \left(D_4/\sqrt{3} + D_2\right)\right]\left\{\frac{S_0 Q_0^2}{2} - \pi_1 \Omega_3 \frac{\rho_W^2}{2}\left[\left(W_3 - W_4\right)\delta\cos\epsilon - \left(W_3 + W_4\right)\delta\sin\epsilon - Z_W\right]\right\}}\right\} ;$$

$$\delta = \frac{P_W}{\sqrt{\left(\frac{Y_W P_W^2}{2} + \frac{1}{\Omega_3}\,\frac{R_c Q_c^2}{2}\right)^2 + \left(\frac{Z_W P_W^2}{2} + \frac{1}{\Omega_3}\,\frac{S_c Q_c^2}{2}\right)}} \;;$$

$$\epsilon = \mathrm{TAN}^{-1}\frac{(W_3 - W_4)\left[\frac{Y_W P_W^2}{2} + \frac{1}{\Omega_3}\,\frac{R_c Q_c^2}{2}\right] - (W_3 + W_4)\left[\frac{Z_W P_W^2}{2} + \frac{1}{\Omega_3}\,\frac{S_c Q_c^2}{2}\right]}{(W_3 - W_4)\left[\frac{Y_W P_W^2}{2} + \frac{1}{\Omega_3}\,\frac{R_c Q_c^2}{2}\right] + (W_3 - W_4)\left[\frac{Z_W P_W^2}{2} + \frac{1}{\Omega_3}\,\frac{S_c Q_c^2}{2}\right]}$$

$$\gamma = \frac{\quad}{\sqrt{\left\{\frac{R_D Q_D^2}{2} - \pi_1 \Omega_3 \frac{P_W^2}{2}\left[(W_3 + W_4)\,\delta\cos\epsilon - (W_3 - W_4)\,\delta\sin\epsilon - Y_W\right]\right\}^2 + \left\{\frac{S_D Q_D^2}{2} - \pi_1 \Omega_3 \frac{P_W^2}{2}\left[(W_3 - W_4)\,\delta\cos\epsilon - (W_3 + W_4)\,\delta\sin\epsilon - Z_W\right]\right\}^2}}$$

$$\eta = \sqrt{\frac{2}{\left(C_3/\pi_3 + C_1\right)^2 + \left(C_4/\pi_3 + C_2\right)^2}} \;; \qquad \vartheta = \mathrm{TAN}^{-1}\frac{\left(C_3/\pi_3 + C_1\right) - \left(C_4/\pi_3 + C_2\right)}{\left(C_3/\pi_3 + C_1\right) + \left(C_4/\pi_3 + C_2\right)}$$

$$\lambda = \eta \cdot \delta \cdot \gamma \;; \qquad \phi = \vartheta + \epsilon + \psi$$

```
      SAMPLE INPUT TO PROGRAM 1
      1.0        1.0        .17       1.65        4.0
      .25        .25       .193      140.0      140.0        75.0
     .667       1.67       .667

      SAMPLE OUTPUT FROM PROGRAM 1
   .41250    1.42767    1.29723    2.25890   -1.63005     2.18189
   .28021     .33777   22.07677  -24.51029    1.42767      .53511
  2.25890   -1.63005    2.18189     .28021     .21986    20.60052
-22.29368   11.15752    5.57533     .34396
```

SAMPLE INPUT TO PROGRAM 2

```
   .41250    1.42767    1.29723    2.25890   -1.63005    2.18189
   .28021     .33777   22.07677  -24.51029    1.42767     .53511
  2.25890   -1.63005    2.18189     .28021     .21986   20.60052
-22.29368   11.15752    5.57533     .34396
      90.         89.
      82.         -4.
      93.         -3.
     102.         -2.
     110.         -1.
     114.          0.
     115.          1.
     111.          2.
     104.          3.
      99.          4.
      90.         93.
      77.         -4.
      80.         -3.
      83.         -2.
      89.         -1.
      96.          0.
     110.          1.
     124.          2.
     135.          3.
     141.          4.
      90.         93.
     126.         -4.
     125.         -3.
     117.         -2.
     108.         -1.
      92.          0.
      93.          1.
      95.          2.
      95.          3.
      94.          4.
      90.         83.1
      77.         -4.
      80.         -3.
      83.         -2.
      87.         -1.
```

90.	0.
93.	1.
94.	2.
95.	3.
94.	4.
90.	100.5
106.	-4.
119.	-3.
129.	-2.
137.	-1.
142.	0.
144.	1.
140.	2.
132.	3.
120.	4.

SAMPLE OUTPUT FROM PROGRAM 2

EXPOSURE SOUTH

TI= 90.00000DEGREES F. TM= 89.00000DEGREES F.

TE DGRS F	THETA HRS	TO DGRS F	Q/A BTU/HR FT2	THETA+PH2/15 HR	MINS
82.00000	-4.00000	89.94869	-.08465	4	32.9
93.00000	-3.00000	89.95005	-.08241	5	32.9
102.00000	-2.00000	89.95116	-.08057	6	32.9
110.00000	-1.00000	89.95215	-.07894	7	32.9
114.00000	.00000	89.95265	-.07812	8	32.9
115.00000	1.00000	89.95277	-.07791	9	32.9
111.00000	2.00000	89.95228	-.07873	10	32.9
104.00000	3.00000	89.95141	-.08016	11	32.9
99.00000	4.00000	89.95079	-.08118	12	32.9

EXPOSURE WEST

TI= 90.00000DEGREES F. TM= 93.00000DEGREES F.

TE DGRS F	THETA HRS	TO DGRS F	Q/A BTU/HR FT2	THETA+PH2/15 HR	MINS
77.00000	-4.00000	90.14934	.24642	4	32.9
80.00000	-3.00000	90.14972	.24703	5	32.9
83.00000	-2.00000	90.15009	.24765	6	32.9
89.00000	-1.00000	90.15083	.24887	7	32.9
96.00000	.00000	90.15170	.25030	8	32.9
110.00000	1.00000	90.15343	.25316	9	32.9
124.00000	2.00000	90.15516	.25602	10	32.9
135.00000	3.00000	90.15652	.25827	11	32.9
141.00000	4.00000	90.15727	.25949	12	32.9

EXPOSURE EAST

TI= 90.00000DEGREES F. TM= 93.00000DEGREES F.

TE DGRS F	THETA HRS	TO DGRS F	Q/A BTU/HR FT2	THETA+PH2/15 HR	MINS
126.00000	-4.00000	90.15541	.25643	4	32.9
125.00000	-3.00000	90.15529	.25622	5	32.9
117.00000	-2.00000	90.15430	.25459	6	32.9
108.00000	-1.00000	90.15318	.25275	7	32.9
92.00000	.00000	90.15120	.24948	8	32.9
93.00000	1.00000	90.15132	.24969	9	32.9
95.00000	2.00000	90.15157	.25010	10	32.9
95.00000	3.00000	90.15157	.25010	11	32.9
94.00000	4.00000	90.15145	.24989	12	32.9

EXPOSURE NORTH

TI= 90.00000DEGREES F. TM= 83.00000DEGREES F.

TE DGRS F	THETA HRS	TO DGRS F	Q/A BTU/HR FT2	THETA+PH2/15 HR	MINS
77.00000	-4.00000	89.64615	-.58384	4	32.9
80.00000	-3.00000	89.64652	-.58323	5	32.9
83.00000	-2.00000	89.64689	-.58261	6	32.9
87.00000	-1.00000	89.64739	-.58180	7	32.9
90.00000	.00000	89.64776	-.58118	8	32.9
93.00000	1.00000	89.64813	-.58057	9	32.9
94.00000	2.00000	89.64825	-.58037	10	32.9
95.00000	3.00000	89.64838	-.58016	11	32.9
94.00000	4.00000	89.64825	-.58037	12	32.9

HORIZONTAL ROOF

TI= 90.00000DEGREES F. TM= 100.00000DEGREES F.

TE DGRS F	THETA HRS	TO DGRS F	Q/A BTU/HR FT2	THETA+PH2/15 HR	MINS
106.00000	-4.00000	90.50517	.83353	4	32.9
119.00000	-3.00000	90.50678	.83619	5	32.9
129.00000	-2.00000	90.50802	.83823	6	32.9
137.00000	-1.00000	90.50901	.83986	7	32.9
142.00000	.00000	90.50963	.84088	8	32.9
144.00000	1.00000	90.50987	.84129	9	32.9
140.00000	2.00000	90.50938	.84048	10	32.9
132.00000	3.00000	90.50839	.83884	11	32.9
120.00000	4.00000	90.50690	.83639	12	32.9

SAMPLE INPUT TO PROGRAM 3

```
1.0      .17      .0      1.65      4.0
.25      .193     0.0     140.0     75.0     0.0
.667     0.0      2.33
 85.      89.
 82.      -4.
 93.      -3.
102.      -2.
110.      -1.
114.       0.
115.       1.
111.       2.
104.       3.
 99.       4.
 85.      93.
 77.      -4.
 80.      -3.
 83.      -2.
 89.      -1.
 96.       0.
110.       1.
124.       2.
135.       3.
141.       4.
 85.      93.
126.      -4.
125.      -3.
117.      -2.
108.      -1.
 92.       0.
 93.       1.
 95.       2.
 95.       3.
 94.       4.
 85.      83.
 77.      -4.
 80.      -3.
 83.      -2.
 87.      -1.
 90.       0.
 93.       1.
```

94.	2.
95.	3.
94.	4.
85.	100.
106.	-4.
119.	-3.
129.	-2.
137.	-1.
142.	0.
144.	1.
140.	2.
132.	3.
120.	4.

SAMPLE OUTPUT FROM PROGRAM 3

EXPOSURE SOUTH

TI= 85.00000DEGREES F. TM= 89.00000DEGREES F.

TE DGRS F	THETA HRS	TO DGRS F	Q/A BTU/HR FT2	THETA+PH2/15 HR	MINS
82.00000	-4.00000	85.15868	.26182	6	31.9
93.00000	-3.00000	85.15945	.26309	7	31.9
102.00000	-2.00000	85.16007	.26413	8	31.9
110.00000	-1.00000	85.16063	.26505	9	31.9
114.00000	.00000	85.16091	.26551	10	31.9
115.00000	1.00000	85.16098	.26562	11	31.9
111.00000	2.00000	85.16070	.26516	12	31.9
104.00000	3.00000	85.16021	.26436	1	31.9
99.00000	4.00000	85.15986	.26378	2	31.9

EXPOSURE WEST

TI= 85.00000DEGREES F. TM= 93.00000DEGREES F.

TE DGRS F	THETA HRS	TO DGRS F	Q/A BTU/HR FT2	THETA+PH2/15 HR	MINS
77.00000	-4.00000	85.31722	.52341	6	31.9
80.00000	-3.00000	85.31743	.52376	7	31.9
83.00000	-2.00000	85.31764	.52411	8	31.9
89.00000	-1.00000	85.31806	.52480	9	31.9
96.00000	.00000	85.31855	.52560	10	31.9
110.00000	1.00000	85.31952	.52722	11	31.9
124.00000	2.00000	85.32050	.52883	12	31.9
135.00000	3.00000	85.32127	.53010	1	31.9
141.00000	4.00000	85.32169	.53079	2	31.9

EXPOSURE EAST

TI= 85.00000DEGREES F. TM= 93.00000DEGREES F.

TE DGRS F	THETA HRS	TO DGRS F	Q/A BTU/HR FT2	THETA+PH2/15 HR	MINS
126.00000	-4.00000	85.32064	.52906	6	31.9
125.00000	-3.00000	85.32057	.52895	7	31.9
117.00000	-2.00000	85.32001	.52803	8	31.9
108.00000	-1.00000	85.31939	.52699	9	31.9
92.00000	.00000	85.31827	.52515	10	31.9
93.00000	1.00000	85.31834	.52526	11	31.9
95.00000	2.00000	85.31848	.52549	12	31.9
95.00000	3.00000	85.31848	.52549	1	31.9
94.00000	4.00000	85.31841	.52537	2	31.9

EXPOSURE NORTH

TI= 85.00000DEGREES F. TM= 83.00000DEGREES F.

TE	THETA	TO	Q/A	THETA+PH2/15
DGRS F	HRS	DGRS F	BTU/HR FT2	HR MINS
77.00000	-4.00000	84.91999	-.13200	6 31.9
80.00000	-3.00000	84.92020	-.13166	7 31.9
83.00000	-2.00000	84.92041	-.13131	8 31.9
87.00000	-1.00000	84.92069	-.13085	9 31.9
90.00000	.00000	84.92090	-.13050	10 31.9
93.00000	1.00000	84.92111	-.13016	11 31.9
94.00000	2.00000	84.92118	-.13004	12 31.9
95.00000	3.00000	84.92125	-.12993	1 31.9
94.00000	4.00000	84.92118	-.13004	2 31.9

HORIZONTAL ROOF

TI= 85.00000DEGREES F. TM= 100.00000DEGREES F.

TE	THETA	TO	Q/A	THETA+PH2/15
DGRS F	HRS	DGRS F	BTU/HR FT2	HR MINS
106.00000	-4.00000	85.59731	.98556	6 31.9
119.00000	-3.00000	85.59821	.98706	7 31.9
129.00000	-2.00000	85.59891	.98821	8 31.9
137.00000	-1.00000	85.59947	.98913	9 31.9
142.00000	.00000	85.59982	.98971	10 31.9
144.00000	1.00000	85.59996	.98994	11 31.9
140.00000	2.00000	85.59968	.98948	12 31.9
132.00000	3.00000	85.59912	.98856	1 31.9
120.00000	4.00000	85.59828	.98717	2 31.9

XKO = Thermal conductivity of concrete, roomside layer BTU/hr ft F

XKL = Thermal conductivity of concrete, outside layer BTU/hr ft F

XKM = Thermal conductivity of earth layer BTU/hr ft F

HO = Inside air film coefficient of heat transfer, BTU/hr ft^2 F

HL = Outdoor air film coefficient of heat transfer, BTU/hr ft^2 F

CO = Specific heat of concrete, roomside layer BTU/lb F

CL = Specific heat of concrete, outside layer BTU/lb F

CM = Specific heat of earth layer BTU/lb F

RHOO = Density of concrete, roomside layer lb/ft^3

RHOL = Density of concrete, outside layer lb/ft^3

RHOM = Density of earth layer lb/ft^3

XLO = Thickness of roomside layer ft

XLL = Thickness of outside layer ft

XLM = Thickness of earth layer ft

TI = Inside air temperature F

TM = Average sol-air temperature

TE = Sol-air temperature

THETA = Time, measured in hours after noon

TO = Roomside wall temperature F

Q/A = Instantaneous rate of heat transfer from roomside surface BTU/hr ft^2

THETA + PH 2/15 = Time of day at which TO and Q/A occur as a result of TE at time THETA (PH2/15 equals lag time in hours)

PROGRAM 1

```
1 READ 101,XKO,XKL,XKM,HO,HL
  READ 101,CO,CL,CM,RHOO,RHOL,RHOM
  READ 101,XLO,XLM,XLL
  PI1=HO/HL
  PI2=XLO*((0.1309*RHOO*CO/XKO)**(0.5))
  PI3=(XKO/HO)*((0.1309*RHOO*CO/XKO)**(0.5))
  SW1=COS(PI2)
  SW2=(EXP(PI2)+EXP(-PI2))*(.5)
  SW3=SIN(PI2)
  SW4=(EXP(PI2)-EXP(-PI2))*(.5)
  C1 =(SW1*SW2)+(SW3*SW4)
  C2 =(SW1*SW2)-(SW3*SW4)
  C3 =SW3*SW2
  C4 =SW1*SW4
  QC=(((C3/PI3)+C1)**(2))+(((C4/PI3)+C2)**(2))
  QC=((2.)/QC)**(0.5)
  RC=(C1+(2.*PI3*C4))*((C3/PI3)+C1)
  RC=RC+((C2-(2.*PI3*C3))*((C4/PI3)+C2))
  SC=(C2-(2.*PI3*C3))*((C3/PI3)+C1)
  SC=SC-((C1+(2.*PI3*C4))*((C4/PI3)+C2))
  GAM2=XLL*((0.1309*RHOL*CL/XKL)**(.5))
  GAM3=(XKL/HL)*((0.1309*RHOL*CL/XKL)**(.5))
  SW1=COS(GAM2)
  SW2=(EXP(GAM2)+EXP(-GAM2))*(.5)
  SW3=SIN(GAM2)
  SWJ=(EXP(GAM2)-EXP(-GAM2))*(.5)
```

```
      D1 =(SW1*SW2)+(SW3*SW4)
      D2 =(SW1*SW2)-(SW3*SW4)
      D3 =SW3*SW2
      D4 =SW4*SW4
      SW1=(D3/GAM3)+D1
      SW1=SW1*SW1
      SW2=(D4/GAM3)+D2
      SW2=SW2*SW2
      QD=SW1+SW2
      QD=(2./QD)**(.5)
      RD=(D1+(2.*GAM3*D4))*((D3/GAM3)+D1)
      RD=RD+((D2-(2.*GAM3*D3))*((D4/GAM3)+D2))
      SD=(D2-(2.*GAM3*D3))*((D3/GAM3)+D1)
      SD=SD-((D1+(2.*GAM3*D4))*((D4/GAM3)+D2))
    3 XLKS=(XLO/XKO)+(XLL/XKL)+(XLM/XKM)
      OMG2=((0.1309*RHOM*CM/XKM)**(.5))*XLM
      OMG3=(XKM/HO)*(0.1309*RHOM*CM/XKM)**(.5)
      PUNCH 101,PI1,PI2,PI3,C1,C2,C3
      PUNCH 101,C4,QC,RC,SC,GAM2,GAM3
      PUNCH 101,D1,D2,D3,D4,QD,RD
      PUNCH 101,SD,XLKS,OMG2,OMG3
      GO TO 1
  101 FORMAT(6F10.5)
      END
```

```
C          PROGRAM 2
      1 READ 101,PI1,PI2,PI3,C1,C2,C3
        READ 101,C4,QC,RC,SC,GAM2,GAM3
        READ 101,D1,D2,D3,D4,QD,RD
        READ 101,SD,XLKS,OMG2,OMG3
        SW1=(EXP(OMG2)+EXP(-OMG2))*(.5)
        SW2=(EXP(OMG2)-EXP(-OMG2))*(.5)
        SW3=SIN(OMG2)
        SW4=COS(OMG2)
        W1=SW4*SW1+SW3*SW2
        W2=SW4*SW1-SW3*SW2
        W3=SW3*SW1
        W4=SW4*SW2
        PW=(W3*W3)+(W4*W4)
        PW=(2./PW)**(.5)
        ZW=W2*W3-W1*W4
        YW=W1*W3+W2*W4
        SW1=(C3/PI3)+C1
        SW2=(C4/PI3)+C2
        ATA=(SW1*SW1)+(SW2*SW2)
        ATA=(2./ATA)**(.5)
        UPS=(C3/PI3)+C1+(C4/PI3)+C2
        UPS=((C3/PI3)+C1-(C4/PI3)-C2)/UPS
        UPS=ATAN(UPS)
        SW4=(PW*PW)*(.5)
        SW5=QC*QC
        SW6=OMG3*2.
        SW3=(YW*SW4)+(RC*SW5/SW6)
        SW1=SW3*SW3
        SW7=(ZW*SW4)+(SC*SW5/SW6)
        SW2=SW7*SW7
        DEL=PW/((SW1+SW2)**(.5))
        SW1=SW3
        SW2=(W3+W4)*SW1
        SW4=(W3-W4)*SW7
        SW4=SW2+SW4
        SW5=(W3-W4)*SW1
        SW6=(W3+W4)*SW7
        SW6=SW5-SW6
        SW6=SW6/SW4
```

```
      EPS=ATAN(SW6)
      SW3=COS(EPS)
      SW4=SIN(EPS)
      SW5=PW*PW
      SW6=QD*QD*(.5)
      SW1=(W3+W4)*DEL*SW3
      SW1=SW1-((W3-W4)*DEL*SW4)-YW
      SW1=PI1*OMG3*SW5*SW1*(.5)
      SW1=(RD*SW6)-SW1
      SW1=SW1*SW1
      SW2=(W3-W4)*DEL*SW3
      SW2=SW2-((W3+W4)*DEL*SW4)-ZW
      SW2=PI1*OMG3*SW5*SW2*(.5)
      SW2=(SD*SW6)-SW2
      SW2=SW2*SW2
      SW2=(SW1+SW2)**(.5)
      GAMA=QD/SW2
      SW7=D3/GAM3+D1
      SW8=D4/GAM3
      SW1=((W3-W4)*DEL*COS(EPS))-((W3+W4)*DEL*SIN(EPS))-ZW
      SW1=PI1*OMG3*PW*PW*SW1*(.5)
      SW1=(SD*QD*QD*(.5))-SW1
      SW2=(SW7-SW8-D2)*SW1
      SW3=(W3+W4)*DEL*COS(EPS)-(W3-W4)*DEL*SIN(EPS)-YW
      SW3=PI1*OMG3*PW*PW*SW3*(.5)
      SW3=(RD*QD*QD*(.5))-SW3
      SW4=(SW7+SW8+D2)*SW3
      SW5=SW2+SW4
      SW6=(SW7-SW8-D2)*SW3
      SW6=SW6-((SW7+SW8+D2)*SW1)
      SW6=SW6/SW5
      PSI=ATAN(SW6)
      XLAM=ATA*DEL*GAMA
  205 PHI=(UPS+EPS+PSI)*(180.)/(3.1416)
      IF(PHI)6,4,4
    6 PHI=360.+PHI
    4 DO 7 J=1,5
    5 READ 101,TI,TM
      PUNCH 102,TI,TM
      PUNCH 106
```

```
      PUNCH 103
      DO 7 I=1,9
      READ 101,TE,THT
      SW4=THT+(PHI/15.)
      IF(SW4)30,31,31
   30 SW4=24.+SW4
   31 TMM=TI+((.606*(TM-TI))/(.856+XLKS))
      TO=TMM+(XLAM*(TE-TM))
      QDA=1.65*(TO-TI)
      IM=SW4
      SW1=IM
      SW2=SW4-SW1
      SW3=(60.)*SW2
   13 IF(IM-12)10,10,11
   11 IM=IM-12
      GO TO 13
   10 PUNCH 104,TE,THT,TO,QDA,IM,SW3
    7 CONTINUE
      PAUSE
      GO TO 1
  101 FORMAT(6F10.5)
  102 FORMAT(3HTI=F10.5,10HDEGREES F.,1X3HTM=F10.5,10HDEGREES F.)
  103 FORMAT(4X6HDGRS F,7X3HHRS,9X6HDGRS F,11H BTU/HR FT2,3H
      HR,5H MINS)
  104 FORMAT(2F10.5,5X2F10.5,13,F5.1)
  106 FORMAT(8X2HTE,5X5HTHETA,13X2HTO,7X3HQ/A,2X12HTHETA+PH2/15)
      END
```

```
C         PROGRAM 3
    1 READ 101,XKO,XKL,XKM,HO,HL
      READ 101,CO,CL,CM,RHOO,RHOL,RHOM
      READ 101,XLO,XLM,XLL
      PI1=HO/HL
      PI2=XLO*((0.1309*RHOO*CO/XKO)**(0.5))
      PI3=(XKO/HO)*((0.1309*RHOO*CO/XKO)**(0.5))
      SW1=COS(PI2)
      SW2=(EXP(PI2)+EXP(-PI2))*(.5)
      SW3=SIN(PI2)
      SW4=(EXP(PI2)-EXP(-PI2))*(.5)
      C1 =(SW1*SW2)+(SW3*SW4)
      C2 =(SW1*SW2)-(SW3*SW4)
      C3 =SW3*SW2
      C4 =SW1*SW4
      QC=(((C3/PI3)+C1)**(2))+(((C4/PI3)+C2)**(2))
      QC=((2.)/QC)**(0.5)
      RC=(C1+(2.*PI3*C4))*((C3/PI3)+C1)
      RC=RC+((C2-(2.*PI3*C3))*((C4/PI3)+C2))
      SC=(C2-(2.*PI3*C3))*((C3/PI3)+C1)
      SC=SC-((C1+(2.*PI3*C4))*((C4/PI3)+C2))
      GAM2=XLL*((0.1309*RHOL*CL/XKL)**(.5))
      GAM3=(XKL/HL)*((0.1309*RHOL*CL/XKL)**(.5))
      SW1=COS(GAM2)
      SW2=(EXP(GAM2)+EXP(-GAM2))*(.5)
      SW3=SIN(GAM2)
      SWJ=(EXP(GAM2)-EXP(-GAM2))*(.5)
      D1 =(SW1*SW2)+(SW3*SW4)
      D2 =(SW1*SW2)-(SW3*SW4)
      D3 =SW3*SW2
      D4 =SW1*SW4
      SW1=(D3/GAM3)+D1
      SW1=SW1*SW1
      SW2=(D4/GAM3)+D2
      SW2=SW2*SW2
      QD=SW1+SW2
      QD=(2./QD)**(.5)
      RD=(D1+(2.*GAM3*D4))*((D3/GAM3)+D1)
      RD=RD+((D2-(2.*GAM3*D3))*((D4/GAM3)+D2))
      SD=(D2-(2.*GAM3*D3))*((D3/GAM3)+D1)
```

```
      SD=SD-((D1+(2.*GAM3*D4))*((D4/GAM3)+D2))
    2 XLKS=(XLO/XKO)+(XLL/XKL)
      SW1=(SD*QD/QC)+(PI1*SC*QC/QD)
      SW1=SW1*SW1
      SW2=(RD*QD/QC)+(PI1*RC*QC/QD)
      SW2=SW2*SW2
      SW2=SW1+SW2
      XLAM=SW2**(.5)
      XLAM=(2.)/XLAM
      SW1=(SD*QD*QD)+(PI1*SC*QC*QC)
      SW2=(D4/GAM3)+D2
      SW3=(D3/GAM3)+D1
      SW4=(RD*QD*QD)+(PI1*RC*QC*QC)
      SW5=((SW3+SW2)*SW4)+((SW3-SW2)*SW1)
      SW6=((SW3-SW2)*SW4)-((SW3+SW2)*SW1)
      SW6=SW6/SW5
      SW6=ATAN(SW6)
      SW1=(C4/PI3)+C2
      SW2=(C3/PI3)+C1
      SW3=SW2+SW1
      SW4=SW2-SW1
      SW4=SW4/SW3
      SW4=ATAN(SW4)
  203 PHI=(SW6+SW4)*(180.)/(3.1416)
      IF(PHI)6,4,4
    6 PHI=360.+PHI
    4 DO 7 J=1,5
    5 READ 101,TI,TM
      PUNCH 102,TI,TM
      PUNCH 106
      PUNCH 103
      DO 7 I=1,9
      READ 101,TE,THT
      SW4=THT+(PHI/15.)
      IF(SW4)30,31,31
   30 SW4=24.+SW4
   31 TMM=TI+((.606*(TM-TI))/(.856+XLKS))
      TO=TMM+(XLAM*(TE-TM))
      QDA=1.65*(TO-TI)
      IM=SW4
```

```
      SW1=IM
      SW2=SW4-SW1
      SW3=(60.)*SW2
   13 IF(IM-12)10,10,11
   11 IM=IM-12
      GO TO 13
   10 PUNCH 104,TE,THT,TO,QDA,IM,SW3
    7 CONTINUE
      PAUSE
      GO TO 1
  101 FORMAT(6F10.5)
  102 FORMAT(3HTI=F10.5,10HDEGREES F.,1X3HTM=F10.5,10HDEGREES F.)
  103 FORMAT(4X6HDGRS F,7X3HHRS,9X6HDGRS F,11H BTU/HR FT2,3H
      HR,5H MINS)
  104 FORMAT(2F10.5,5X2F10.5,I3,F5.1)
  106 FORMAT(8X2HTE,5X5HTHETA,13X2HTO,7X3HQ/A,2X12hTHETA+PH2/15)
      END
```

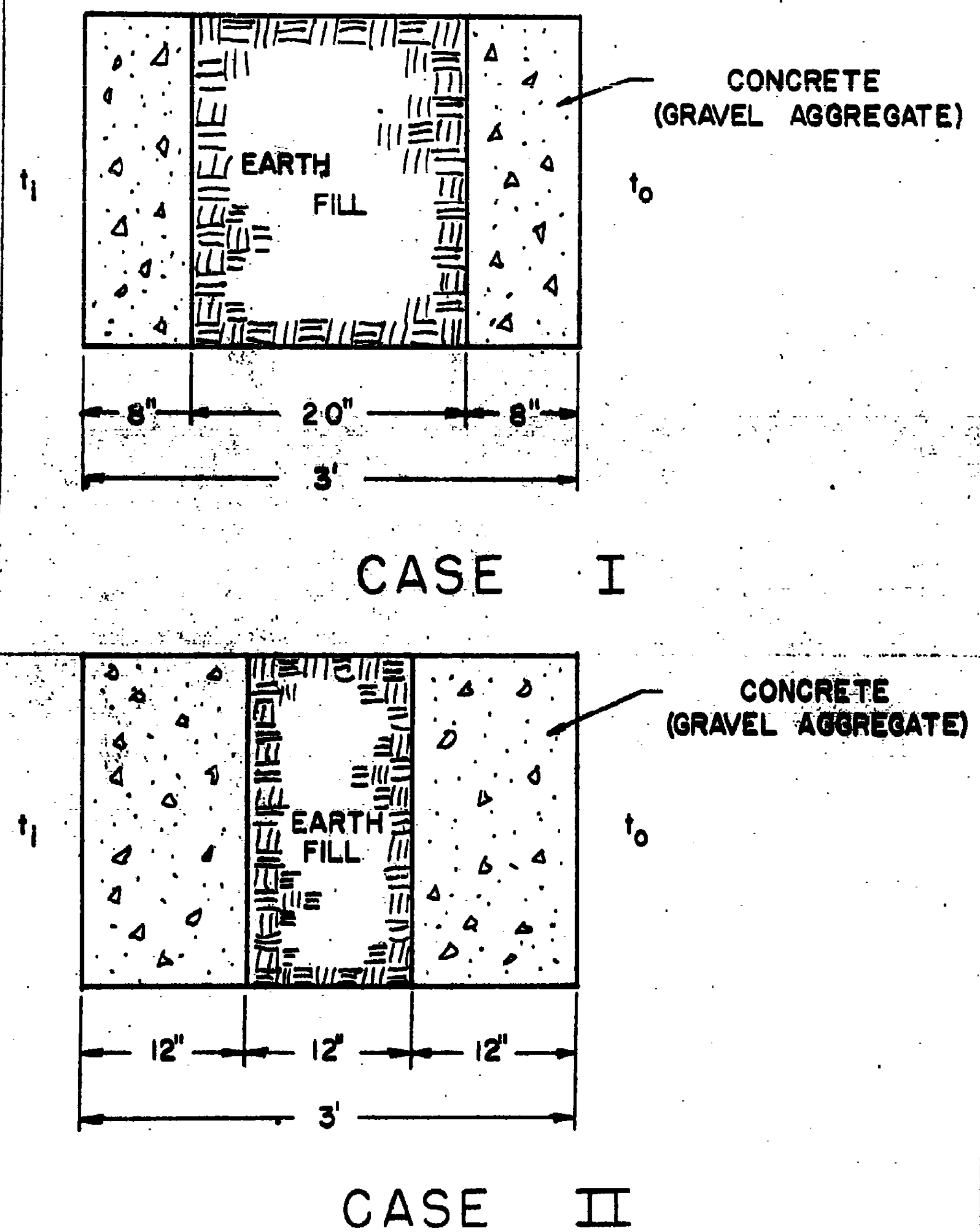


Figure 1b. Concrete-earth configurations.

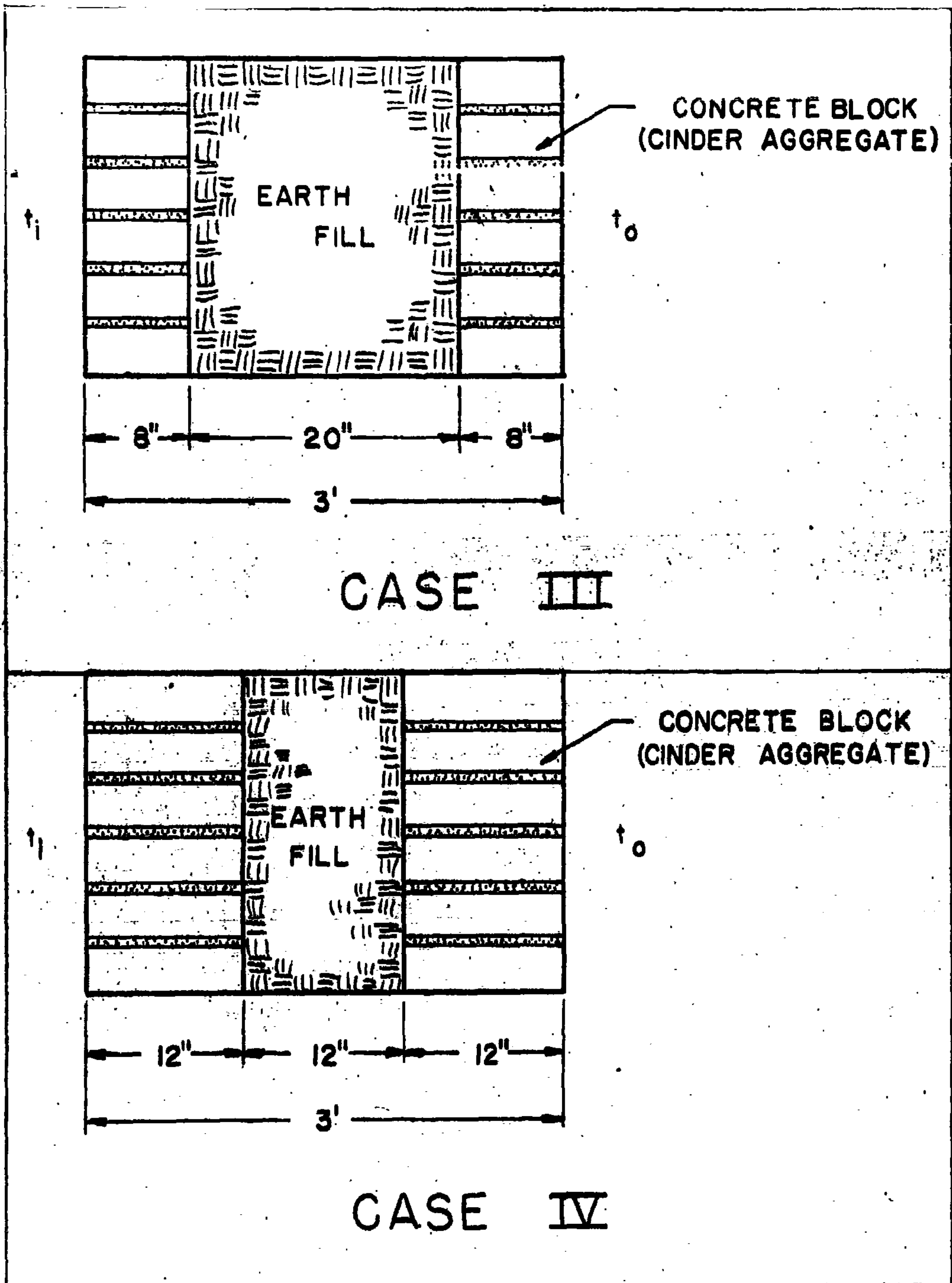
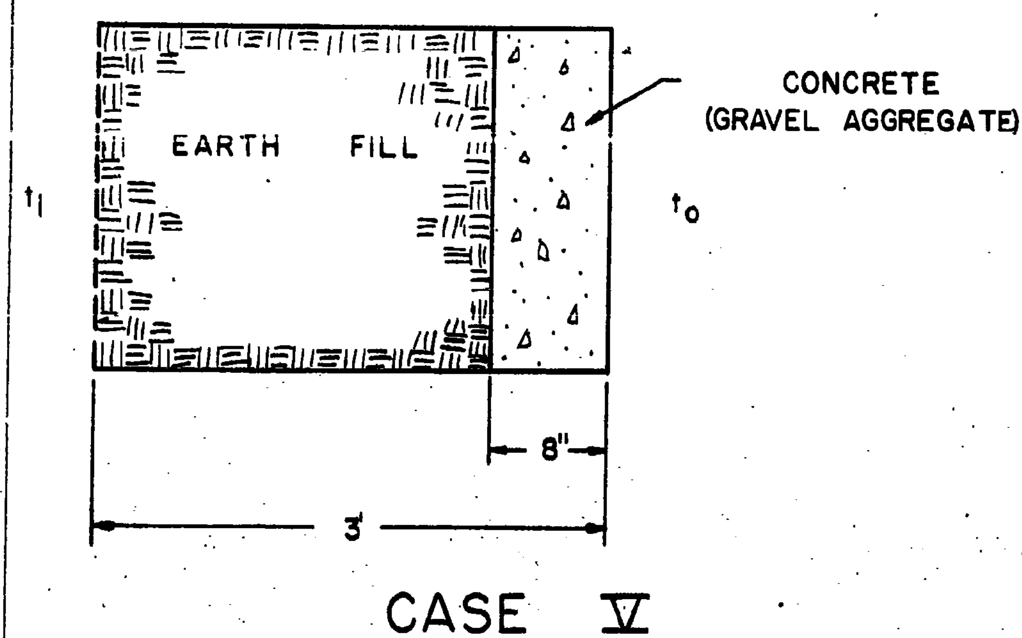


Figure 2b. Concrete-earth configurations.



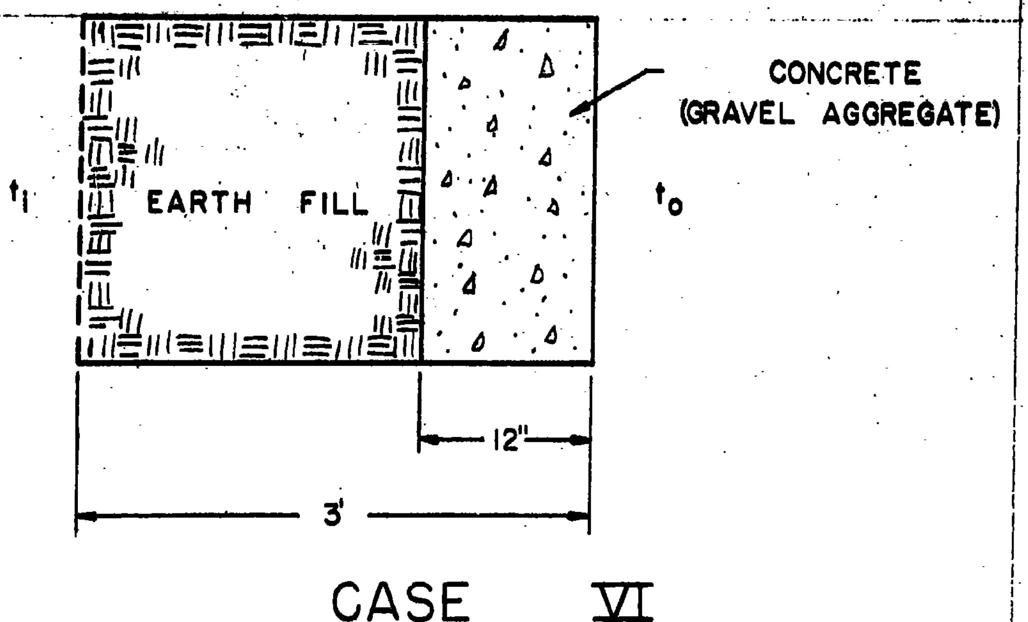
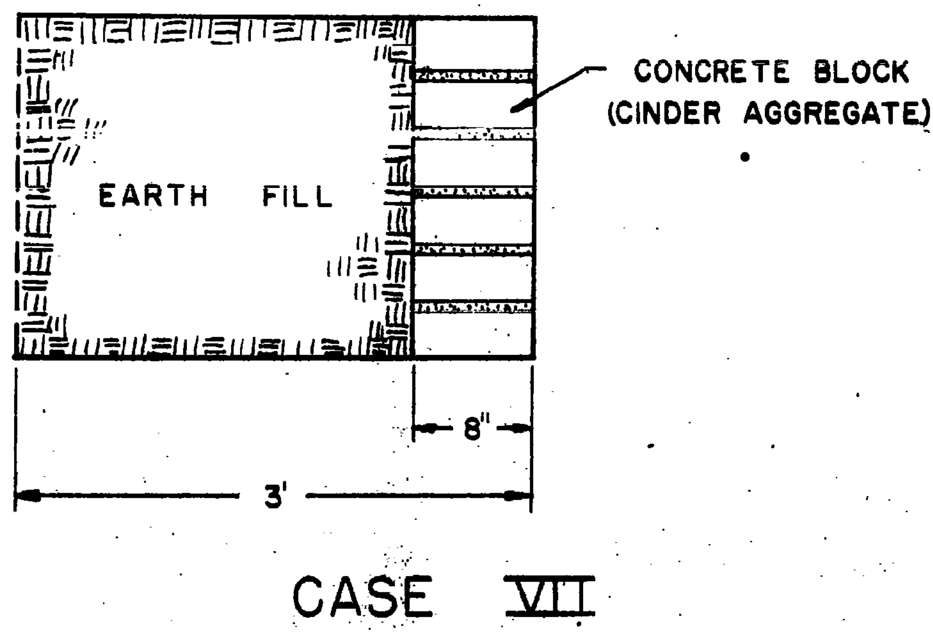


Figure 3b. Concrete-earth configurations.



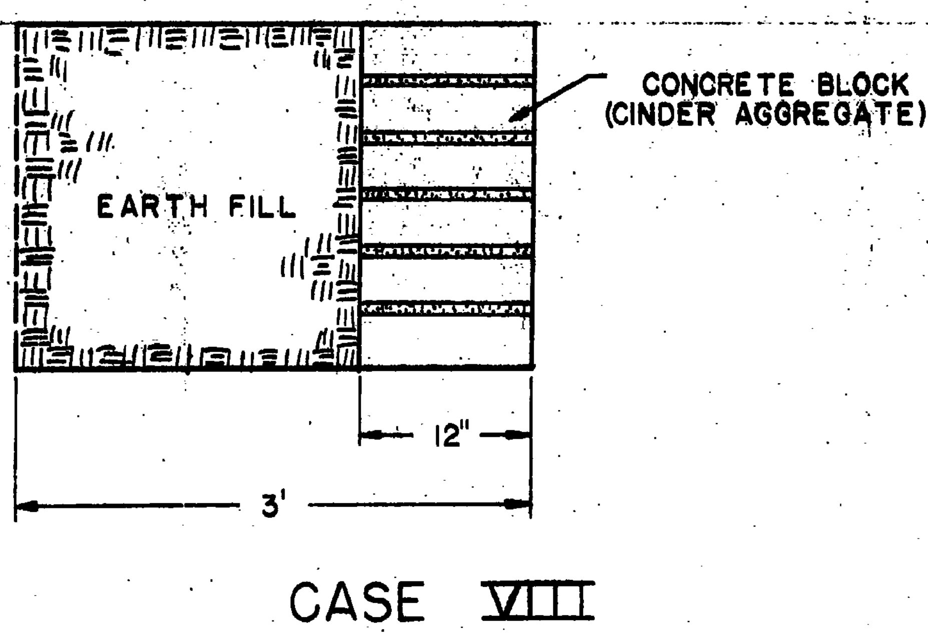


Figure 4b. Concrete-earth configurations.

Appendix C

Table IC. Heat Transfer Through Heavy Wall Construction for 90 F Inside Temperature

Exposure*	8 AM	10 AM	12 Noon	2 PM	4 PM
BTU/hr/sq ft - Cases IA, IIIA, IVA, VA, VIA, VIIA, VIIIA					
South	-.0754	-.0731	-.0718	[illegible]	[illegible]
West	.222	.223	.224	.227	.229
East	.228	.226	.224	.224	.224
North	-.523	-.522	-.521	-.521	-.521
Roof	.747	.749	.751	.750	.748
BTU/hr/sq ft - Cases IIA, IIIB, IVB, IVC, VIIIB					
South	-.155	-.108	-.081	-.088	-.115
West	.378	.392	.422	.487	.526
East	.491	.471	.413	.420	.417
North	-.983	-.969	-.953	-.944	-.944
Roof	1.399	1.452	1.486	1.478	1.431
BTU/hr/sq ft - Cases IB, IIB, IIIC, VB, VIB, VIIB, VIIIC					
South	-.249	-.191	-.158	-.166	-.200
West	.641	.658	.695	.774	.823
East	.780	.754	.683	.692	.689
North	-1.618	-1.601	-1.581	-1.570	-1.570
Roof	2.30	2.36	2.41	2.40	2.34
BTU/hr/sq ft - Cases IC, IIC					
South	-.403	-.158	-.001	-.049	-.196
West	.757	.830	.989	1.33	1.54
East	1.35	1.24	.940	.977	.964
North	-2.30	-2.22	-2.14	-2.09	-2.09
Roof	3.25	3.52	3.71	3.66	3.42

*North Latitude

Table IC. Heat Transfer Through Heavy Wall Construction for 90 F Inside Temperature (cont'd)

Exposure*	8 AM	10 AM	12 Noon	2 PM	4 PM
	BTU/hr/sq ft - Cases VIC, VIIC				
South	-.342	-.011	.187	.138	-.061
West	.414	.513	.728	1.191	1.473
East	1.225	1.075	.662	.712	.695
North	-1.683	-1.584	-1.468	-1.402	-1.402
Roof	2.36	2.74	2.99	2.92	2.59
	BTU/hr/sq ft - Case VC				
South	-.617	.141	.597	.483	.028
West	.447	.675	1.168	2.23	2.88
East	2.31	1.965	1.016	1.130	1.092
North	-2.69	-2.46	-2.19	-2.04	-2.04
Roof	3.74	4.61	5.18	5.03	4.27

*North Latitude

Appendix C

Table IIC. Heat Transfer Through Heavy Wall Construction for 85 F Inside Temperature

Exposure*	8 AM	10 AM	12 Noon	2 PM	4 PM
BTU/hr/sq ft - Cases IA, IIIA, IVA, VA, VIA, VIIA, VIIIA					
South	.331	.336	.338	.337	.335
West	.663	.663	.666	.672	.675
East	.673	.670	.666	.666	.666
North	-.168	-.166	-.165	-.164	-.164
Roof	1.250	1.254	1.257	1.257	1.253
BTU/hr/sq ft - Cases IIA, IIIB, IVB, IVC, VIIIB					
South	.538	.584	.611	.605	.577
West	1.071	1.085	1.115	1.180	1.219
East	1.184	1.164	1.106	1.113	1.110
North	-.291	-.277	-.261	-.252	-.252
Roof	2.091	2.145	2.179	2.171	2.124
BTU/hr/sq ft - Cases IIIC, VIIB					
South	.571	.668	.730	.711	.653
West	1.133	1.162	1.225	1.360	1.442
East	1.369	1.330	1.205	1.220	1.215
North	-.331	-.303	-.269	-.249	-.249
Roof	2.298	2.410	2.472	2.481	2.366
BTU/hr/sq ft - Cases IB, VB, VIB, VIIIC					
South	.778	.893	.967	.944	.876
West	1.546	1.580	1.654	1.814	1.912
East	1.826	1.774	1.723	1.649	1.643
North	-.444	-.409	-.369	-.342	-.345
Roof	3.104	3.235	3.310	3.321	3.184

*North Latitude

Table IIC. Heat Transfer Through Heavy Wall Construction for 85 F Inside Temperature (cont'd)

Exposure*	8 AM	10 AM	12 Noon	2 PM	4 PM
BTU/hr/sq ft - Cases IC, IIB, IIC, VIIC					
South	1.184	1.428	1.585	1.538	1.392
West	2.345	2.417	2.576	2.917	3.125
East	2.942	2.832	2.527	2.564	2.552
North	-.708	-.635	-.549	-.498	-.498
Roof	4.835	5.115	5.274	5.298	5.006
BTU/hr/sq ft - Cases VC, VIC					
South	1.139	1.878	2.359	2.211	1.767
West	2.023	2.425	2.906	3.941	4.569
East	4.015	3.682	2.758	2.869	2.832
North	-.921	-.699	-.440	-.290	-.290
Roof	5.462	6.313	6.867	6.719	5.980

*North Latitude

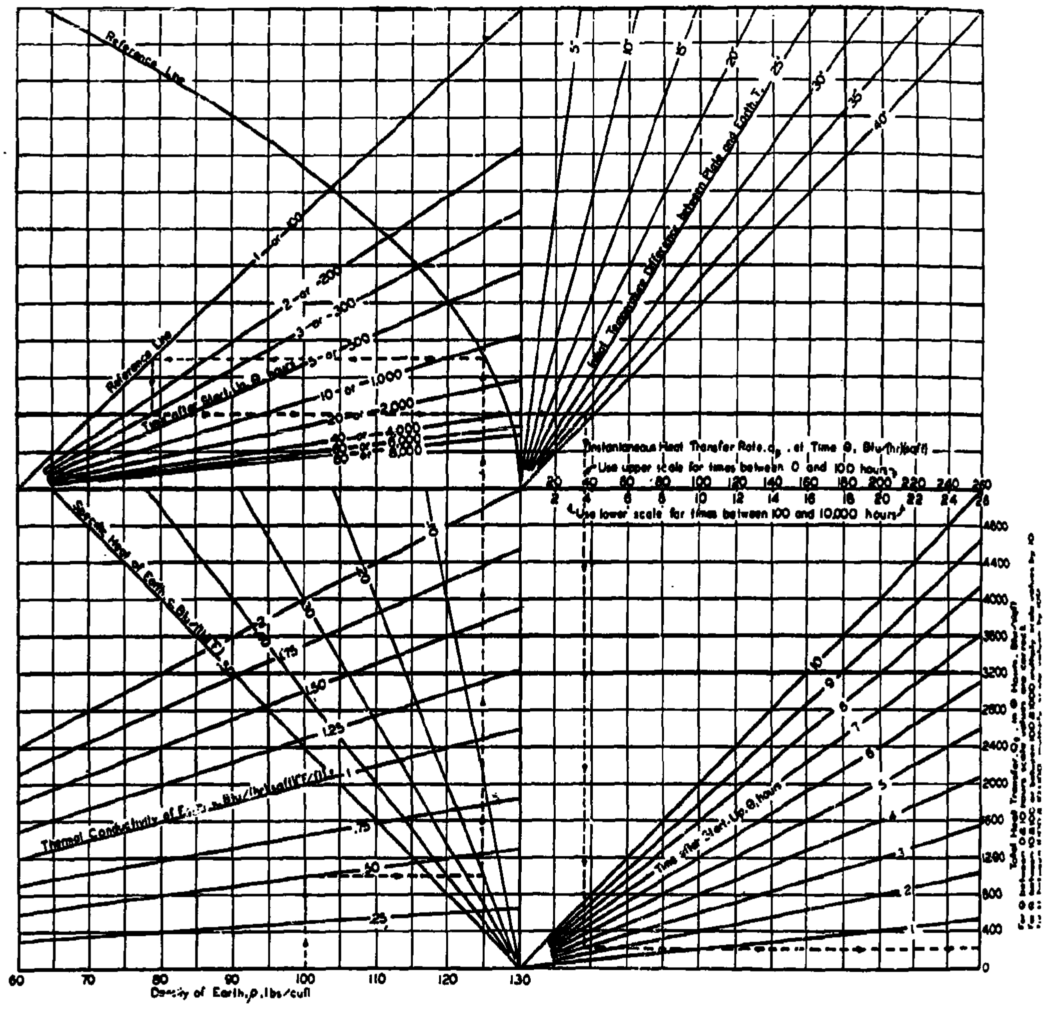


Figure 1. Graphical solution for equation (a).

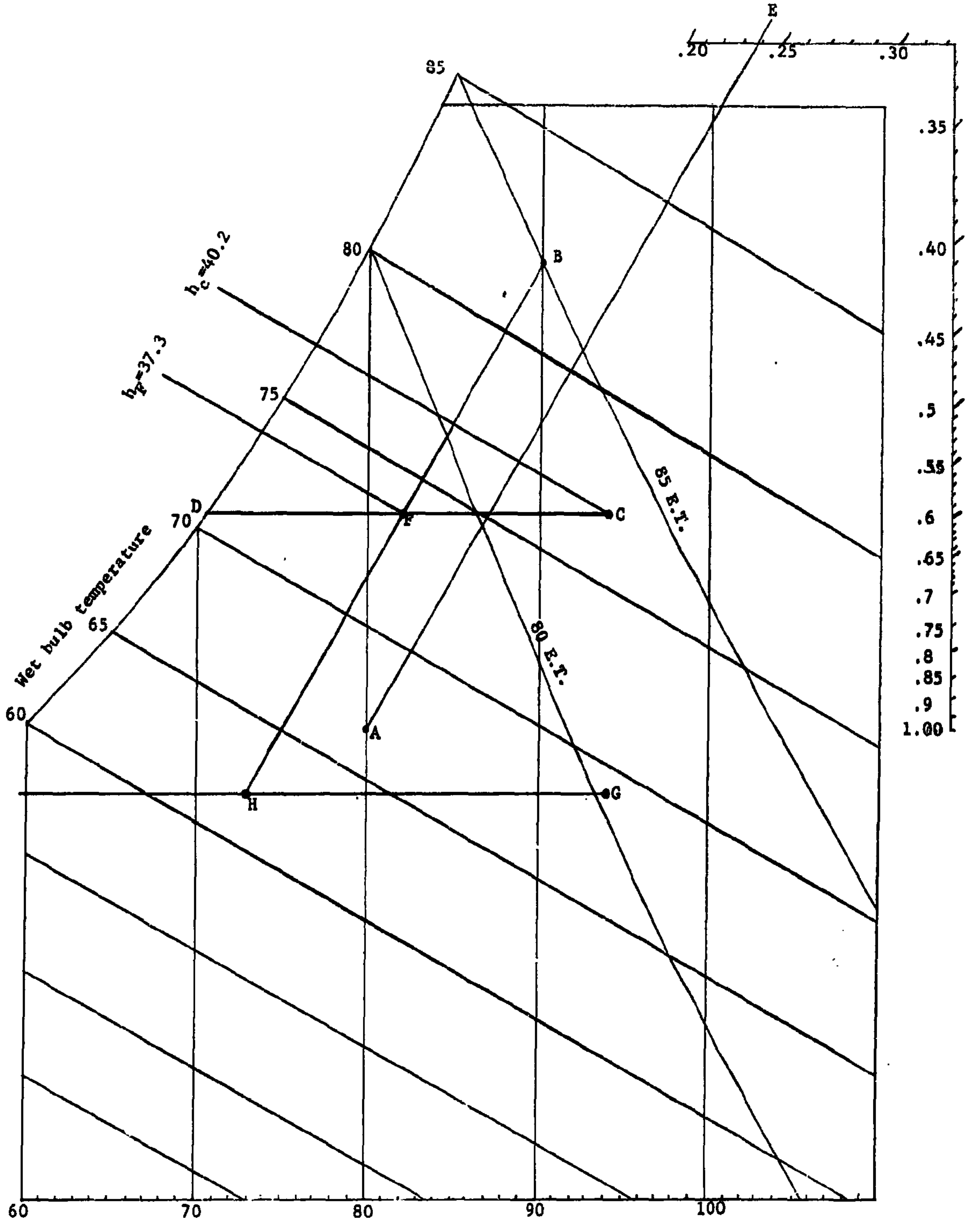


Figure 2. Modified psychrometric chart.